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Cluster Formation and Evolution on Semiconductor Surfaces

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- b. \* Number of papers published in refereed journals (list attached): 44
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Graduate Students: 10

Post-Doctoral Associates: 6

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Female Post-Doctoral Associates: 0

the number of

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Minority\* Post-Doctoral Associates: 0

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## **Part I**

### **a. Papers Submitted to Refereed Journals (and not yet published)**

1. Y.-N. Yang, Y.S. Luo, and J.H. Weaver, "An STM Study of Ge/GaAs(110) I: Initial Nucleation and Growth," Phys. Rev. B (in press).
2. Y.-N. Yang, Y.S. Luo, and J.H. Weaver, "An STM Study of Ge/GaAs(110) II: Coalescence and Layer-by-Layer Growth," Phys. Rev. B (in press).
3. Y.S. Luo, Y.-N. Yang, J.H. Weaver, L.T. Florez, and C.J. Palmstrøm, "Multi-Orientational Growth of Al on GaAs(001) Studied with STM," Phys. Rev. B (submitted 10/7/92).

### **b. Papers Published in Refereed Journals**

1. C.M. Aldao, I.M. Vitomirov, G.D. Waddill, S.G. Anderson, and J.H. Weaver, "Dynamic Coupling Model: Temperature-, Dopant-Concentration, and Coverage-Dependent Schottky Barrier Formation," Phys. Rev. B **41**, 2800-2812 (1990).
2. G.D. Waddill, I.M. Vitomirov, C.M. Aldao, S.G. Anderson, C. Capasso, J.H. Weaver, and Z. Liliental-Weber, "Abrupt Interfaces with Novel Structural and Electronic Properties: Metal Cluster Deposition and Metal-Semiconductor Junctions," Phys. Rev. B **41**, 5293-5305 (1990).
3. T.J. Wagener, H.M. Meyer, Y. Hu, M.B. Jost, J.H. Weaver, and K.C. Goretta, "O 2p Holes: Temperature Effects and Surface Characteristics of Cuprate Superconductors," Phys. Rev. B **41**, 4201-4211 (1990).
4. C.M. Aldao, G.D. Waddill, P.J. Benning, C. Capasso, and J.H. Weaver, "Photovoltaic Effects in Temperature-Dependent Fermi Level Movement for GaAs(110)," Phys. Rev. B Rapid Commun. **41**, 6092-6095 (1990).
5. I.M. Vitomirov, C.M. Aldao, G.D. Waddill, C. Capasso, and J.H. Weaver, "Metal-InP(110) Schottky Barriers: Temperature-, Dopant-Concentration-, and Cluster Dependencies," Phys. Rev. B **41**, 8465-8476 (1990).
6. G.D. Waddill, C.M. Aldao, C. Capasso, P.J. Benning, Yongjun Hu, T.J. Wagener, M.B. Jost, and J.H. Weaver, "Thermally-Reversible Band Bending for Bi/GaAs(110): Photoemission and Inverse Photoemission Investigations," Phys. Rev. B **41**, 5960-6968 (1990).
7. G.D. Waddill, T. Komeda, Y.-N. Yang, and J.H. Weaver, "Photoemission from Metal Dots on GaAs(110): Surface Photovoltages and Surface Conductance," Phys. Rev. B Rapid Commun. **41**, 10283-10286 (1990).
8. T.R. Ohno, J.C. Patrin, H.M. Meyer, J.H. Weaver, Y. Kimachi, and Y. Hidaka, "Atom- and Cluster-Assembled Interfaces: Cr/Bi<sub>2</sub>Sr<sub>2-x</sub>Ca<sub>1+x</sub>Cu<sub>2</sub>O<sub>8+y</sub>," Phys. Rev. B Rapid Commun. **41**, 11677-11680 (1990).
9. T.R. Ohno, Y.-N. Yang, J.H. Weaver, Y. Kimachi, and Y. Hidaka, "Ge on Bi<sub>2</sub>Sr<sub>2-x</sub>Ca<sub>1+x</sub>Cu<sub>2</sub>O<sub>8+y</sub>: Reduced Reactivity through Cluster Assembly," Appl. Phys. Lett. **57**, 718-720 (1990).
10. Z. Liliental-Weber, E.R. Weber, J. Washburn, and J.H. Weaver, "Schottky Barrier Contacts on Defect-Free GaAs(110)," Appl. Phys. Lett. **56**, 2507-2509 (1990).

11. J.H. Weaver and G.D. Waddill, "Cluster Assembly of Interfaces: Nanoscale Engineering," *Science* **251**, 1444-1451 (1991).
12. T.R. Ohno, Y.-N. Yang, G.H. Kroll, K. Krause, L.D. Schmidt, Y. Kimachi, Y. Hidaka, S.H. Pan, and A.L. de Lozanne, "Cluster-Assembled Overlayers on High Temperature Superconductors," *Phys. Rev. B* **43**, 7980-7990 (1991).
13. B.M. Trafas, D.M. Hill, P.J. Benning, G.D. Waddill, Y.-N. Yang, R.L. Siefert, and J.H. Weaver, "Clustering and Reaction for Cr/GaAs(110): Scanning Tunneling Microscopy and Photoemission," *Phys. Rev. B* **43**, 7174-7184 (1991).
14. T. Komeda, G.D. Waddill, P.J. Benning, and J.H. Weaver, "Photoelectron Microscopy and Photoelectron Spectroscopy of  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8(100)$ ," *Phys. Rev. B Rapid Commun.* **43**, 8713-8716 (1991).
15. T.R. Ohno, J.C. Patrin, U.S. Ayyala, and J.H. Weaver, "Ag Deposition onto Xe: Clustering, Incorporation, and Surface Attraction," *Phys. Rev. B* **44**, 1891-1895 (1991).
16. Y.-N. Yang, B.M. Trafas, R.L. Siefert, and J.H. Weaver, "Effect of Nonthermally-activated Hopping on Overlayer Morphology: An STM Study of Ti/GaAs(110)," *Phys. Rev. B* **44**, 5720-5725 (1991).
17. Y.Z. Li, J.C. Patrin, M. Chander, and J.H. Weaver, "Rare Earth Growth Structures on GaAs(110): Ce, Sm, and Yb," *Phys. Rev. B* **44**, 12903-12907 (1991).
18. T. Komeda, F. Stepniak, and J.H. Weaver, "Schottky-Limit Barrier Heights for CO-Coated Metal Clusters on GaAs(110)," *Appl. Phys. Lett.* **58**, 2809-2811 (1991).
19. G.D. Waddill, T. Komeda, P.J. Benning, and J.H. Weaver, "Photoelectron Microscopy and Spectroscopy using Synchrotron Radiation," *J. Vac. Sci. Technol. A* **9**, 1634-1639 (1991).
20. T. Komeda, S.G. Anderson, J.M. Seo, M.C. Schabel, and J.H. Weaver, "Sm/GaAs(110) Interface Formation: Surface Instabilities and Kinetic Constraints," *J. Vac. Sci. Technol. A* **9**, 1964-1971 (1991).
21. P.J. Benning, J.L. Martins, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Electronic Structure of  $\text{K}_x\text{C}_{60}$ : Insulating, Metallic, and Superconducting Character," *Science* **252**, 1417-1419 (1991).
22. Y.Z. Li, M. Chander, J.C. Patrin, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Order and Disorder in  $\text{C}_{60}$  and  $\text{K}_x\text{C}_{60}$  Multilayers: Direct Imaging with Scanning Tunneling Microscopy," *Science* **253**, 429-433 (1991).
23. D.M. Poirier, T.R. Ohno, G.H. Kroll, Y. Chen, P.J. Benning, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Formation of Fullerides and Fullerene-Based Heterostructures," *Science* **253**, 646-648 (1991).
24. C.M. Aldao, I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Effects of Growth Temperature on Atom Distributions, Fermi-Level Positions, and Valence-Band Offsets for Ge/n-type InP(110) Heterojunctions," *Phys. Rev. B* **43**, 13592-13596 (1991).
25. P.J. Benning, D.M. Poirier, N. Troullier, J.L. Martins, J.H. Weaver, R.E. Haufler, L.P.F. Chibante, and R.E. Smalley, "Electronic States of Solid  $\text{C}_{60}$ : Symmetries and Photoionization Cross Sections," *Phys. Rev. B Rapid Commun.* **44**, 1962-1965 (1991).
26. M.B. Jost, N. Troullier, D.M. Poirier, J.L. Martins, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Empty Electronic States and Band Dispersion in Solid  $\text{C}_{60}$ : Inverse Photoemission and Theory," *Phys. Rev. B Rapid Commun.* **44**, 1966-1969 (1991).

27. T.R. Ohno, Y. Chen, S.E. Harvey, G.H. Kroll, J.H. Weaver, R.E. Haufler, and R.E. Smalley, " $C_{60}$  Bonding and Energy Level Alignment on Metal and Semiconductor Surfaces," *Phys. Rev. B* **44**, 13747-13755 (1991).
28. G.H. Kroll, P.J. Benning, T.R. Ohno, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Interaction of  $O_2$  with  $C_{60}$ : Photon-Induced Oxidation," *Chem. Phys. Lett.* **181**, 112-116 (1991).
29. M.B. Jost, P.J. Benning, D.M. Poirier, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Occupied and Unoccupied Electronic States of Solid  $C_{70}$  with Comparison to  $C_{60}$ ," *Chem. Phys. Lett.* **184**, 423-427 (1991).
30. J.M. Seo, Y. Chen, and J.H. Weaver, "Oxide Films Grown on GaAs(110) at 20 K: Stability during Cr Overlayer Formation," *J. Appl. Phys.* **70**, 4336-4341 (1991).
31. J.C. Patrin, Y.Z. Li, and J.H. Weaver, "Cluster Growth of Al on Stepped and Unstepped GaAs(110) at 300 K: A Scanning Tunneling Microscopy Examination," *Phys. Rev. B* **45**, 1756-1761 (1992).
32. Y.-N. Yang, Y.S. Luo, and J.H. Weaver, "Ag Crystallite Formation and Coalescence on Hydrogen-terminated GaAs(110)," *Phys. Rev. B* **45**, 3606-3611 (1992).
33. Y.-N. Yang, Y.S. Luo, and J.H. Weaver, "Anisotropic Kinetics in Overlayer Growth: An STM Study of Ge/GaAs(110)," *Phys. Rev. B Rapid Commun.* **45**, 13803-13806 (1992).
34. Y.Z. Li, M. Chander, J.C. Patrin, and J.H. Weaver, "Scanning Tunneling Microscopy and Spectroscopy for Individual  $C_{60}$  Molecules on Si(111)," *Phys. Rev. B Rapid Commun.* **45**, 13837-13840 (1992).
35. J.H. Weaver, "Electron Spectroscopies of Fullerenes and Fullerides," *J. Phys. Chem. Solids* **53**, 1433-1447 (1992).
36. T.R. Ohno, G.H. Kroll, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Yb and Yb-K-Fulleride Formation, Bonding, and Electrical Character," *Phys. Rev. B* **46**, 10437-10441 (1992).
37. T. Guo, M.D. Diener, Y. Chai, M.J. Alford, R.E. Haufler, S.M. McClure, T.R. Ohno, J.H. Weaver, G.E. Scuseria, and R.E. Smalley, "Uranium Stabilization of  $C_{28}$ : A Tetravalent Fullerene," *Science* **257**, 1661-1664 (1992).
38. J.H. Weaver, "Fullerenes and Fullerides: Photoemission and Scanning Tunneling Microscopy Studies," *Accounts of Chemical Research* **25**, 143-149 (1992).
39. T.R. Ohno, G.H. Kroll, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Doping of  $C_{60}$  with Iodine," *Nature* **355**, 401 (1992).
40. C. Gu, F. Stepniak, D.M. Poirier, M.B. Jost, P.J. Benning, Y. Chen, T.R. Ohno, J.L. Martins, J.H. Weaver, J. Fure, and R.E. Smalley, "Metallic and Insulating Phases of  $Li_xC_{60}$ ,  $Na_xC_{60}$ , and  $Rb_xC_{60}$ ," *Phys. Rev. B Rapid Commun.* **45**, 6348-6351 (1992).
41. P.J. Benning, D.M. Poirier, T.R. Ohno, Y. Chen, M.B. Jost, F. Stepniak, G.H. Kroll, J.H. Weaver, J. Fure, and R.E. Smalley, " $C_{60}$  and  $C_{70}$  Fullerenes and Potassium Fullerides," *Phys. Rev. B* **45**, 6899-6909 (1992).
42. Y. Chen, F. Stepniak, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Fullerides of Alkaline Earth Metals," *Phys. Rev. B Rapid Commun.* **45**, 8845-8848 (1992).

43. J.H. Weaver, Y. Chai, T.R. Ohno, G.H. Kroll, C. Jin, R.E. Haufler, T. Guo, J.M. Alford, J. Conceicao, L.P.F. Chibante, G.A. Palmer, and R.E. Smalley, "Carbon-Caged Metal Atoms," *Chem. Phys. Lett.* **190**, 460-464 (1992).
44. C.M. Aldao, A. Palermo, and J.H. Weaver, "Calculated Photocurrents and Surface Barrier Heights," *J. Vac. Sci. Technol. A* **10**, 493-496 (1992).

**c. Books (and sections thereof) Submitted for Publication**

1. C.M. Aldao and J.H. Weaver "Atomic-Scale Chemistry of Metal-Semiconductor Interfaces," Chapter xx in *Contacts to Semiconductor Surfaces*, edited by L.J. Brillson (Noyes Publication, New Jersey, 1992).
2. J.H. Weaver, G.D. Waddill, I.M. Vitomirov, and C.M. Aldao, "Cluster-Assembled Interfaces," Chapter xx in *On Clusters and Clustering: From Atoms to Fractals*, edited by Peter J. Reynolds (North Holland, 1992).

**d. Books (and sections thereof) Published**

1. J.H. Weaver, Z. Lin, and F. Xu, "Surface Segregation at Evolving Metal/Semiconductor Interfaces," Chapter 10 in *Surface Segregation Phenomena*, edited by P.A. Dowben and A. Miller (CRC Press, Boca Raton, 1990) pp. 259-289.
2. H.M. Meyer and J.H. Weaver, "Electronic Structure, Surface Properties, and Interface Chemistry of High Temperature Superconductors," Chapter 6 in *Physical Properties of High Temperature Superconductors II*, edited by D.M. Ginsberg (World Scientific, 1990) pp 369-457.
3. J.H. Weaver, "The Formation and Properties of Metal-Semiconductor Interfaces," Chapter 8 in *Electronic Materials: A New Era of Materials Science*, edited by J.R. Chelikowsky and A. Franciosi (Springer-Verlag, 1991) pp 135-214.

**e. Technical Reports Published and Papers Published in Non-Refereed Journals**

1. G.D. Waddill, T.R. Ohno, and J.H. Weaver, "Clusters and Cluster Assembly of Interfaces," Proceedings of the 1990 Fall Meeting of the Materials Research Society.
2. J.H. Weaver, "Clusters, Their Growth, and Their Interaction with Surfaces," Naval Research Reviews, Office of Naval Research, Three / 1991, Vol. XLIII, pp 16-27.
3. Y.Z. Li and J.H. Weaver, "Direct Imaging of Fullerenes using Scanning Tunneling Microscopy," *Research and Development Magazine*, Vol. 33, December 1991, pp 38-40.

**f. Patents Filed**

None

**g. Patents Granted**

None

#### **h. Invited Presentations at Topical or Scientific/Technical Society Conferences**

1. J.H. Weaver, "Adatom Interactions on Semiconductor Surfaces," American Vacuum Society, College Station, September 1989.
2. J.H. Weaver, "Physics and Chemistry of Metal/Semiconductor Interfaces," International Conference on Semiconductor and Integrated Circuit Technology, Beijing, October 1989. [Conference cancelled]
3. J.H. Weaver, "Temperature-, Dopant-Concentration-, and Coverage-Dependent Schottky Barrier Formation," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
4. J.H. Weaver, "Metal/Semiconductor Interfaces: Temperature-Dependent Atom and Cluster Deposition," Australian Physical Society, Perth, Australia, February 1990. [Unable to attend]
5. J.H. Weaver, "Temperature-, Dopant-Concentration-, and Coverage-Dependent Schottky Barrier Formation," Seventeenth Annual Conference on Physics and Chemistry of Semiconductor Interfaces," Clearwater Beach, Florida, February 1990.
6. J.H. Weaver, "Temperature-, Dopant-Concentration-, and Coverage-Dependent Schottky Barrier Formation," Symposium on Metallization for Electronics Applications, Annual Meeting of the Minerals, Metals, and Materials Society, Anaheim, February 1990.
7. J.H. Weaver, "Surfaces and Interfaces of High Temperature Superconductors," March Meeting of the American Physical Society, Anaheim, March 1990.
8. J.H. Weaver, "Metal/Semiconductor Interfaces: Temperature-Dependent Atom and Cluster Deposition," Eighth International Conference on Thin Films (ICTF-8), San Diego, April 1990.
9. J.H. Weaver, "Clusters and Cluster-Assembled Interfaces," Materials Research Society, Boston, November 1990.
10. J.H. Weaver, "Photoemission and STM Studies of  $C_{60}$ ," Annual Meeting of the Minnesota Chapter of the American Vacuum Society, Minneapolis, February 1991.
11. J.H. Weaver, "Occupied and Empty Electronic States of Solid  $C_{60}$  and the Interaction of  $C_{60}$  with the Environment": Photoemission, Inverse Photoemission, and STM," Special Session on  $C_{60}$ , March Meeting of the American Physical Society, Cincinnati, March 1991.
12. J.H. Weaver, "Distinguished Lecturer, NSF Workshop on "Thin Film Science and Technology for the 21st Century," Evanston, IL, July/August 1991.
13. J.H. Weaver, "Clusters and Cluster-Assembled Interfaces," Gordon Conference, Wolfeboro, New Hampshire, August 1991.
14. J.H. Weaver, "Electronic Structure and Properties of  $C_{60}$ ,  $C_{70}$ , and Alkali-Metal Fullerides," American Chemical Society Meeting, New York, August 1991.
15. J.H. Weaver, "Electronic Structure and Properties of  $C_{60}$ ,  $C_{70}$ , and Alkali-Metal Fullerides," Midwest Solid State Conference, Ames, Iowa, September 1991.
16. J.H. Weaver, Plenary Lecture, "Electronic Structure and Properties of  $C_{60}$ ,  $C_{70}$ , and Alkali-Metal Fullerides," European Conference on Surface Science, Stockholm, Sweden, September 1991.



17. J.H. Weaver, "Electronic Structure and Properties of C<sub>60</sub>, C<sub>70</sub>, and Alkali-Metal Fullerides," Engineering Foundation Conference on Fullerenes, January 1992. [Conference cancelled]
18. J.H. Weaver, "Electronic Structure and Properties of C<sub>60</sub>, C<sub>70</sub>, and Alkali-Metal Fullerides," 24th Annual Synchrotron Radiation Center Users Group Meeting, Stoughton, Wisconsin, October 1991.
19. J.H. Weaver, "Electronic Structures and Growth Structures of Fullerenes and Fullerides," 38th National Symposium of the American Vacuum Society, Seattle, November 1991.
20. J.H. Weaver, "Electronic Structures and Growth Structures of Fullerenes and Fullerides," American Chemical Society, Eau Claire, Wisconsin, January 1992.
21. J.H. Weaver, "Electronic Structures and Growth Structures of Fullerenes and Fullerides," International Winterschool on Electronic Properties of High Temperature Superconductors," Kirchberg, Tyrol, Austria, March 1992.
22. J.H. Weaver, "Electronic Structures and Properties of C<sub>60</sub>, C<sub>70</sub>, and Alkali-Metal and Fullerides," American Physical Society, Indianapolis, Indiana, March 1992.
23. J.H. Weaver, "Fullerenes and Fullerides: Photoemission and Scanning Tunneling Microscopy Studies," 94th Annual Meeting and Exposition of the American Ceramic Society, Minneapolis, Minnesota, April 1992.
24. J.H. Weaver, "Electronic Structures and Growth Structures of Fullerenes and Fullerides," 181st Electrochemical Society Meeting, St. Louis, Missouri, May 1992.
25. J.H. Weaver, "Electronic Structures and Properties of C<sub>60</sub>, C<sub>70</sub>, and Metal Fullerides," International Summer Institute for Surface Studies," Milwaukee, Wisconsin, June 1992.
26. J.H. Weaver, "Electronic Structures and Growth Structures of Fullerenes and Fullerides," Gordon Conference on Electron Spectroscopy, Wolfeboro, New Hampshire, July 1992.
27. J.H. Weaver, "Electronic Structures and Properties of C<sub>60</sub>, C<sub>70</sub>, and Metal Fullerides," US/Japan Fermiology Workshop, Sendai, Japan, July 1992.
28. J.H. Weaver, "Clusters and Their Interactions with Surfaces," Sixth International Symposium on Small Particles and Inorganic Clusters," Chicago, Illinois, September 1992.
29. J.H. Weaver, "Electronic Structures and Properties of Fullerenes and Fullerides," Symposium on Nanoscale Science, Sendai, Japan, September 1992.
30. J.H. Weaver, "Electronic Structures and Properties of Fullerenes and Fullerides," Symposium on The Third Form of Carbon: Fullerenes - Properties and Prospects, Annual Meeting of the Minerals, Metals, and Materials Society, Chicago, Illinois, November 1992.
31. J.H. Weaver, "Electronic Structure of C<sub>60</sub> Assemblies," International Symposium on Local Order in Condensed Matter Physics, Orissa, India, December 1992. [insufficiently funded]
32. J.H. Weaver, "Electronic Structures and Properties of C<sub>60</sub>, C<sub>70</sub>, and Metal Fullerides," Symposium on Fullerenes, International Centre of Condensed Matter Physics, Brasilia, Brazil, April 1993.
33. J.H. Weaver, "Electronic Structures and Properties of Fullerenes and Fullerides," US-Japan Workshop on Fullerenes, Honolulu, Hawaii, July 1993.

*i. Contributed Presentations at Topical or Scientific/Technical Society Conferences*

1. C.M. Aldao, M. Vos, and J.H. Weaver, "Interface Formation with Metal Ions and Neutrals: Influence on Interface Morphology and Schottky Barrier for Ag/InP(110)," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
2. G.D. Waddill, C.M. Aldao, and J.H. Weaver, "Symmetric Fermi Level Evolution at Metal-Semiconductor Interfaces: The Role of Substrate Dopant Concentration," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
3. S.G. Anderson, S.J. Severtson, and J.H. Weaver, "Temperature Dependent Al/GaAs(110) Interface Formation and Adatom Energy References," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
4. I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Surface Interactions of Adatoms with GaAs(110): Reversible Temperature Dependent Charge Redistribution," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
5. G.D. Waddill, T. Komeda, P.J. Benning, and J.H. Weaver, "Photoelectron Spectroscopy and Microscopy with Synchrotron Radiation," 37th National Symposium of the American Vacuum Society, Toronto, October 1990.
6. M.B. Jost, Y. Hu, and J.H. Weaver, "Evolution of the Empty Electronic States of Low-Coverage, Oriented, Hexagonal Structures on Bi/InP(110): An Inverse Photoemission Study," 37th National Symposium of the American Vacuum Society, Toronto, October 1990.
7. P.J. Benning, G.D. Waddill, T. Komeda, and J.H. Weaver, "Photoelectron Microscopy and Spectroscopy using Synchrotron Radiation," 23rd Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, November 1990.
8. G.D. Waddill, P.J. Benning, and J.H. Weaver, "Cluster Assembly of Interfaces," 23rd Annual Synchrotron Radiation Center Users Group Meeting, Stoughton, Wisconsin, November 1990.
9. J.C. Patrin, Y.-Z. Li, and J.H. Weaver, "Cluster Growth of Al on GaAs(110) Studied by Scanning Tunneling Microscopy," March Meeting of the American Physical Society, Cincinnati, Ohio, March 1991.
10. Y.Z. Li, J.C. Patrin, M. Chander, and J.H. Weaver, "Scanning Tunneling Microscopy of Ce, Sm, and Yb Structures on GaAs(110)," March Meeting of the American Physical Society, Cincinnati, Ohio, March 1991.
11. P.J. Benning, G.D. Waddill, T. Komeda, and J.H. Weaver, "Photoelectron Spectroscopy using Synchrotron Radiation," 13th Symposium on Applied Surface Analysis, Minneapolis, June 1991.
12. Y.Z. Li, J.C. Patrin, and J.H. Weaver, "Cluster Growth of Al on GaAs(110) Studied by Scanning Tunneling Microscopy," 13th Symposium on Applied Surface Analysis, Minneapolis, June 1991.
13. J.C. Patrin, Y.Z. Li, M. Chander, and J.H. Weaver, "Temperature and Coverage Dependent Structures of Sb on GaAs(110) from Scanning Tunneling Microscopy," 38th Annual American Vacuum Society Symposium, Seattle, October 1991.
14. P.J. Benning, Y. Chen, F. Stepniak, and J.H. Weaver, "Electronic States of Alkali-Metal Fullerenes: Na, K, and Cs in Solid C<sub>60</sub> and C<sub>70</sub>," 38th Annual American Vacuum Society Symposium, Seattle, October 1991.

15. M.B. Jost, P.J. Benning, N. Troullier, D.M. Poirier, J.L. Martins, J.H. Weaver, L.P.F. Chibante, and R.E. Smalley, "Valence and Conduction Band Electronic States in Solid C<sub>60</sub> and C<sub>70</sub>: Inverse Photoemission, Synchrotron Radiation Photoemission, and Theory," 38th Annual American Vacuum Society Symposium, Seattle, October 1991.
16. J.H. Weaver, "Electronic Structure and Properties of C<sub>60</sub>, C<sub>70</sub>, and Alkali-Metal Fullerenes," Workshop on Fullerenes, Philadelphia, August 1991.
17. D.M. Poirier, G.H. Kroll, M.B. Jost, T.R. Ohno, and J.H. Weaver, "Alkali Metal Intercalated C<sub>60</sub> Films Studied with Inverse Photoemission and X-Ray Photoemission," March Meeting of the American Physical Society, Indianapolis, Indiana, March 1992.
18. P.J. Benning, T.R. Ohno, Y. Chen, C. Gu, F. Stepniak, and J.H. Weaver, "Photoemission Studies and Resistivity Measurements of Fulleride Thin Films," March Meeting of the American Physical Society, Indianapolis, Indiana, March 1992.
19. Y.Z. Li, M. Chander, J.C. Patrin, and J.H. Weaver, "Individual and Multilayer C<sub>60</sub> Studied with Scanning Tunneling Microscopy and Spectroscopy," March Meeting of the American Physical Society, Indianapolis, Indiana, March 1992.
20. Y.N. Yang, Y.S. Luo, and J.H. Weaver, "The Impact of Anisotropic Kinetics on Epitaxial Growth: An STM Study of Ge/GaAs(110)," March Meeting of the American Physical Society, Indianapolis, Indiana, March 1992.

***j. Honors/Awards/Prizes***

Physics News in 1990 (American Institute of Physics) for Cluster Assembly of Interfaces.

Physics News in 1991 (American Institute of Physics) for Studies of Fullerenes and Fullerides.

Naval Research Reviews for Studies of Clusters

Elected Fellow of the American Physical Society with a citation that reads "For studies of the fundamental parameters associated with overlayer growth on surfaces, with particular note of the development of cluster assembly as a means of creating novel interface structures."

***k. Number of Graduate Students Receiving Full or Partial Support on ONR Contract***

10

***l. Number of Postdoctoral Fellows Receiving Full or Partial Support on ONR Contract***

6

**Part II****a. Principal Investigator**

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**b. Cognizant ONR Scientific Officer**

Dr. John Pazik

**c. Current telephone number: (612) 625-6548**

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**d. Brief description of project**

This program focused on fundamental problems related to the nucleation and growth of clusters and the interaction of those clusters with surfaces. The issues it addressed were those involved with the deposition of atoms on a surface, particularly the chemical environments created by those atoms and the processes encountered as the number of atoms increases. It investigated cluster formation and cluster-induced reaction, as well as the tendency of clusters to nucleate preferentially at particular defect sites of the surface. It focused on the evolution of clusters into new structures with distinct crystalline character. These issues are of very broad importance because they are encountered when considering the growth of elemental and compound layers on any surface, be they semiconductors, high temperature superconductors, or fullerenes.

**e. Significant results of this project**

Our continuing studies of cluster formation focused on atom deposition at 300 K. In these studies, we emphasized GaAs(110) with the metals Ti, Ce, Sm, Yb, Al, and Ag, and the semiconductor Ge using STM and photoemission. These metals were chosen because they exhibit different chemical reactivities with the surface. In many cases, we found ordered structures at low coverage, but then the triggering of reactive intermixing and compound formation at higher coverage. Our studies demonstrated that the clusters themselves activated the reaction, with ordered structures at low surface density serving as precursors to high density clusters and reaction. A very important point, then, is that a growing overlayer evolves through several stages, each being metastable, and one must explore each state individually to gain the depth of understanding needed to describe the chemical and physical processes at the surface/interface.

Cluster assembly as an alternate growth technique to atom deposition was developed under ONR support, and we continued to examine its ramifications in both basic and applied circumstances. This technique has received considerable attention, drawing invited papers at conferences, a feature article in Science, and recognition in ONR Reviews. Variations in the technique have also been explored, including a detailed study of the forces of interaction between the cluster and the surface in the presence of the buffer layer. In one particularly

intriguing study, we showed that the cladding of metallic clusters of nanoscale dimension with CO prior to deposition on the surface of GaAs(110) produced Fermi level pinning that scaled with the work function of the specific metal cluster, i.e. Schottky-limit behavior. This was important in understanding Fermi level pinning and the role of surface defects.

We have investigated the properties of fullerenes in thin film form, both in their pure state and in their many doped states. This work has been done in conjunction with Richard Smalley's group at Rice. Our unique capabilities have made it possible to explore the full distribution of electronic states of C<sub>60</sub> and C<sub>70</sub> and the effects induced by doping with alkali metals, alkaline earth metals, rare earth metals, iodine, and others. We have examined surface bonding and surface chemistry of the fullerenes, and we have investigated their stability against oxygen and beam degradation. We have enjoyed collaborations with José Luís Martins, a theorist, who has contributed a great deal to the understanding of the physical properties, notably superconductivity in these new high temperature superconductors. We have used STM to explore chemisorption growth structures, virtually defining a new field of surface science and crystal growth. Finally, with the discovery that atoms could be incorporated into fullerenes with relatively high yields, we have used our spectroscopies to examine the nature of the chemical bonding of these new endohedral molecules.

***g. Graduate students and post-doctorals currently working on project***

G.D. Waddill (now Lawrence Livermore National Laboratory)  
 T. Komeda (now Texas Instruments, Japan)  
 T.R. Ohno (now Colorado School of Mines)  
 Y.Z. (Peter) Li, postdoc (now 3M)  
 Y.-N. (Neal) Yang, postdoc (now University of Maryland)  
 Yu Chen, postdoc  
 C.M. Aldao (now University of Mar del Plata)  
 I.M. Vitomirov (now Xerox)  
 S.G. Anderson (now University of Texas-Houston)  
 Y.J. (Jeff) Hu (not University of Washington-Seattle)  
 M.J. Jost, graduate student (now Rosemount)  
 G.H. Kroll, graduate student (now Micron Technologies)  
 S.E. Harvey, graduate student  
 F. Stepniak, graduate student  
 P.J. Benning, graduate student  
 D.M. Poirier, graduate student